Effect of Hydration age on Durability of concrete by using Electrical Resistivity technique.

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Abstract: **The Electrical resistivity technique is one of the popular NDT method used to evaluate the rate of corrosion of embedded steel in concrete by many researchers & practicing Engineers of construction industries. Thus by using Electrical resistivity technique the durability of concrete can be evaluated as the durability of concrete is depends on the permeability of concrete. The permeability of concrete depends on the size, shape, pore size distribution of capillary pore & its connectivity. The permeability of concrete is again depend on the volume of solid formation in pore space due to hydration of cement in concrete. The volume of solid phase in pore space is depend on the age of hydration, thus durability of concrete at different age of hydration is different. In this paper different types of concrete samples were studied for its durability at different age of hydration by using the Electrical resistivity technique. From the experimental results it has revealed that Resistivity of concrete increases with the age of hydration.**

Keywords —PC CEM-I, PCC-CEM-II/A-M, PCC-CEM-II/B-M, CEM-III/A, PPC, Pore size distribution, microstructure, Hydration.

I. INTRODUCTION

The Durability of concrete is depend on the microstructural properties of concrete i.e. size, shape, pore size distribution & its connectivity. Thus durability is directly depend on the permeability of concrete. So any concrete with lesser permeability shows higher durability. The permeability of concrete again depend on the pore size, shape, pore size distribution, connectivity & volume of solid in pore space. The volume of solid phase is again depend on the age of hydration .In this paper different types of concrete samples with different types of cement, varying water content, varying cement content & partial substitution of Portland cement with Pozzolonic materials Fly ash & GGBS in the mixes were examined for its durability at different age of hydration by using Electrical Resistivity technique. The experimental work results show that durability of concrete i.e. the Electrical resistivity of concrete increases with increasing the hydration age of concrete. Hence on increasing the hydration age the volume of solid phase in pore space will increases, which results in improvement of concrete durability by reducing the permeability of concrete.

II. MEASUREMENT TECHNIQUES FOR ELECTRICAL RESISTIVITY OF CONCRETE

The electrical resistivity of concrete is measured by Wenner Four-probe technique. The basic principle involved in this method is to apply current (I) through outer two probes and the potential difference (V) is measured between two inner probes. The current is generally carried by ions in the pore fluid of concrete. The resistivity of concrete is calculated by the equation below.

$$\text{Resistivity } \rho = 2\pi\, aV/I \ [\text{k}\Omega\text{cm}]$$

Where "a" is the distance between the probe.

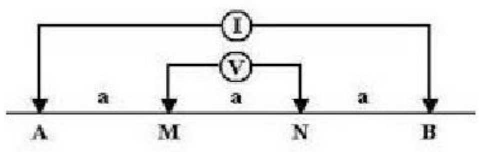

Fig. 1. Wenner four point probe arrangement for ERT.

III. STANDARD RECOMMENDATIONS.

Table-1: Rating of Chloride permeability in concrete by using Electrical Resistivity technique as per AASHTO T-95

Chloride Ions Penetrability level in concrete	Electrical Resistivity range in KΩcm as per AASHTO T-95
High	< 12
Moderate	12-21
Low	21-37
Very Low	37-254
Negligible	>254

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IV. MATERIALS

There are different types of concrete mix (S_1 to S_{22}) were used for this experimental work with different option like changing of Cement type , varying cement content, varying water-cement ratio & partial substitution of Portland with Pozzolonic materials Fly ash & GGBS .The different types of cement used in this research work is Portland cement CEM-I, Portland composite cement (PCC) of type CEM-II/A-M, CEM-II/B-M, Blast-furnace slag cement (BFSC) CEM-III/A as per EN-197-1. & Fly ash based Portland Pozzolana Cement as per IS-1489, Part-I. The pozzolonic materials used in the research experiment work was Pulverized Fly ash (F-type) & Ground granulated Blast furnace slag (GGBS) .The coarse aggregate used for this experimental work was of crushed Basalt rock & Fine aggregate used in the experiment was of river sand having FM of 2.7. The super plasticizer used in this research work was of PCE based super plasticizer. The reference grade of concrete was used for this experimental work was C-30/37 grade with Portland cement (CEM-I, 52.5 N as per BSEN-197, Part-I). The design mix for C-30/37 grade was of Portland cement (CEM-I, 52.5 N) content 438 kg/cum, w/c ratio 0.4, Coarse Aggregate content 1142 kg/cum, Fine Aggregate content 685 kg/ cum & Superplasticiser content 3.50kg/cum .The test results of all the materials used in the experimental work is tabulated below.

Table-2
Physical Properties of different types of Cement & Pozzolonic Materials Fly Ash & GGBS

Cement	Sp Gravity	Fineness in cm2/gm.	% Residue on 45 Micron
PC	3.15	3550	3.87
PCC,CEM-II/A-M	3.12	3635	4.28
PCC,CEM-II/B-M	3.08	3727	4.55
BFSC,CEM-III/A	2.98	4282	5.56
PPC (Fly Ash)	3.01	3825	2.92
Fly Ash	2.145	3704	8.7
GGBS	2.909	3443	7.83

Table-3
Chemical Composition of different types of Cement.

Component	PC	PCC CEM-II/A-M	PCC CEM-II/B-M	BFSC CEM-III/A	PPC (FA-Based)
CaO	63.25	55.47	51.6	53.59	44.38
SiO_2	20.97	25.22	26.23	24.45	29.17
Al_2O_3	5.02	8.27	9.11	8.97	11.47
Fe_2O_3	3.73	3.36	3.66	2.22	3.49
SO_3	2.95	2.64	2.33	2.83	2.75
MgO	2.02	1.85	1.29	2.95	1.94
Na_2O	0.190	0.220	0.270	0.282	0.220
K_2O	0.530	0.510	0.870	0.661	0.640

Table-4
Chemical Composition of Pozzolonic materials Fly Ash & GGBS

Component	Fly Ash	GGBS
CaO	1.86	34.3
SiO_2	61.08	36.03
Al_2O_3	27.58	17.15
Fe_2O_3	5.36	1.03
SO_3	0.11	0.32
MgO	0.14	7.21
Na_2O	0.572	0.140

Table-5
Properties of Course Aggregate.

Parameter	Results
Sp Gravity	2.82
Dry rodded Density in Kg/cum	1675
% of Water absorption	0.45
% of Impact value	12.71
% of Loss Angel Abrasion	0.45
% of Flakiness Index	22.24
% of Elongation Index	21.5
Magnesium Sulphate Soundness in %	12
Combined Gradation (19-4.75 mm)	Satisfied ASTMC-33

Table-6
Properties of Fine Aggregate.

Parameter	Results
Sp Gravity	2.56
75 micron finer in % by weight	1.78
FM	2.71
% Of Water absorption by weight	1.56

Table-7
Mixing Water test results

Test Parameter	Test Results
pH value	7.6
Chloride in mg/L	251
Sulfate in mg/L	1.78
TDS in mg/L	752

V.EXPERIMENTAL SETUP

The samples used for evaluation of durability of concrete by using Electrical Resistivity Technique was 200mm x 100 mm x 100mm plain concrete block of different type of concrete mix as explained in Table-8 . The casted specimens were allowed to cure up to 28-days. & the specimens were tested for durability of concrete by using Wenner four probe electrical resistivity meter as per AASHTO T-95 at 7-days, 14-days, 21-days & 28-days respectively. The mix details of different concrete samples used for experiment is tabulated below.

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Table-8
Mix details of different types of Concrete mix.

Mix ID	Mix Details	Cement Kg/m3	w/c Ratio	CA in Kg/m3	FA in Kg/m3
S_0	CEM-I	438	0.40	1142	685
S_1	CEM-I	438	0.35	1142	685
S_2	CEM-I	438	0.45	1142	685
S_3	CEM-I	438	0.50	1142	685
S_4	CEM-I	438	0.55	1142	685
S_5	CEM-I	350	0.40	1142	685
S_6	CEM-I	375	0.40	1142	685
S_7	CEM-I	400	0.40	1142	685
S_8	CEM-I	425	0.40	1142	685
S_9	CEM-I	450	0.40	1142	685
S_{10}	CEM-II/A-M	438	0.40	1142	685
S_{11}	CEM-II/B-M	438	0.4	1142	685
S_{12}	CEM-III/A	438	0.4	1142	685
S_{13}	PPC	438	0.4	1142	685
S_{14}	CEM-I 90%+10%FA	394.2	0.4	1142	685
S_{15}	CEM-I 85%+15%FA	372.3	0.4	1142	685
S_{16}	CEM-I 80%+20%FA	350.4	0.4	1142	685
S_{17}	CEM-I 75%+25%FA	328.5	0.4	1142	685
S_{18}	CEM-I 70%+30%FA	306.6	0.4	1142	685
S_{19}	CEM-I 70%+30%GGBS	306.6	0.4	1142	685
S_{20}	CEM-I 60%+40%GGBS	262.8	0.4	1142	685
S_{21}	CEM-I 50%+50%GGBS	219	0.4	1142	685
S_{22}	CEM-I 40%+60%GGBS	175.2	0.4	1142	685

Fig. 2. Samples for ERT of concrete.

VI. RESULTS & DISCUSSIONS

The casted specimen were tested for Electrical Resistivity of concrete at different age of curing i.e. hydration like 7-days, 14-days, 21-days & 28-days of curing through Electrical Resistivity technique by using Wenner four probe electrical resistivity meter as per AASHTO T-95. From the experimental outcome it shows that the resistivity of concrete is increases with increase in age of hydration. The results also shows that sample S1 to S4 with increasing water content shows reduction in Electrical resistivity of concrete & Samples S5 to S9 with increasing cement content shows increase in resistivity of concrete. The experiment also revealed the resistivity of concrete with different types of cement such as Electrical Resistivity of concrete mix S12 with Blast furnace Slag Cement CEM-III/A [9] shows maximum resistivity of concrete as compared to other types of cement due to higher % of slag in this cement. The mix with S11 & S13 with other type of cement i.e. PCC-CEM-II/B-M [9] & Fly ash-based PPC [10] respectively also shows higher resistivity than normal Portland cement CEM-I [9]. The results also shows that on partial substitution of Portland cement with pozzolonic materials Fly ash in the mix S14 to S18, there is not very significant changes in Electrical Resistivity of concrete except Mix ID S16 (20% Fly ash) & it also observed that beyond 20% Fly ash the resistivity get reduced, while the concrete samples with GGBS having mix ID S19 to S22 shows high resistivity even at early age 7-days & also at 28-days. The concrete mix with higher the GGBS content in the mix shows higher the resistivity of concrete both at early age & at later age. Thus from the experiment it is clear that Electrical resistivity increases with increase in hydration age & concrete with Slag either in cement or with direct partial substitution of normal Portland cement shows higher resistivity [4]. Hence durability of concrete is directly depend on Electrical resistivity of concrete i.e. more the resistivity of concrete more the concrete is durable.

Table-9: Electrical Resistivity of concrete at different age of Hydration.

Mix ID	ERT at 7-days in KΩcm	ERT at 14-days in KΩcm	ERT at 21-days in KΩcm	ERT at 28-days in KΩcm
S_0	8.5	13.8	14.4	16
S_1	10.6	17.8	18.9	20.3
S_2	9.4	12.2	14	14.8
S_3	10.3	12.4	12.6	12.8
S_4	8.5	8.9	9.6	10.2
S_5	4.7	5.6	6.5	7.9
S_6	5.8	6.4	7.5	8.4
S_7	7.2	7.8	8.7	9.3
S_8	8	8.5	9.5	10.6
S_9	9.2	9.6	10.8	12.3
S_{10}	14.3	15.9	18.8	26.1
S_{11}	15.2	17.8	20.3	32.6
S_{12}	19.2	21.9	28.9	42
S_{13}	16.2	17.1	23.8	34.9
S_{14}	10.1	12.1	15.3	19.4
S_{15}	10.6	13.1	16.2	24.1
S_{16}	14.2	15.4	18.8	33.2
S_{17}	9.2	12.2	13.1	19.7
S_{18}	8.8	10.7	13.6	18.6
S_{19}	22.21	24.6	25.4	31.5
S_{20}	22.6	26.1	30.7	34.7
S_{21}	23.7	32.1	41.2	48.2
S_{22}	25.2	35.1	47.5	53.6

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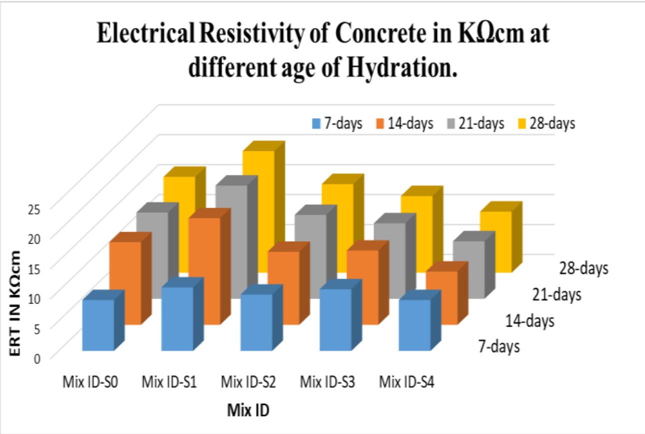

Figure-3: Electrical Resistivity of concrete mix with varying w/c ratio at different age of hydration.

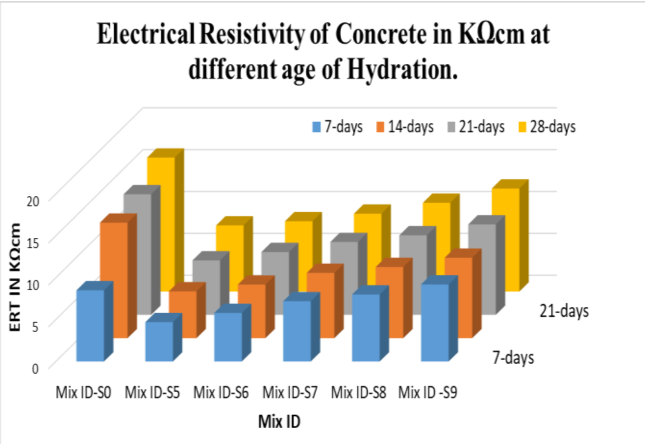

Figure-4: Electrical Resistivity of concrete mix with varying cement content at different age of hydration.

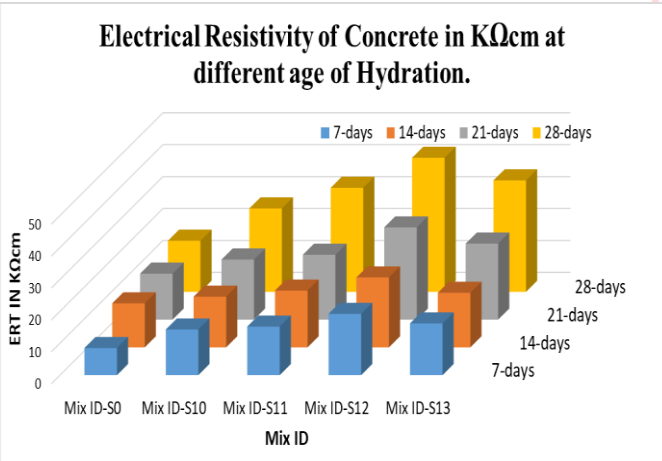

Figure-5: Electrical Resistivity of concrete mix with different types of cement at different age of hydration.

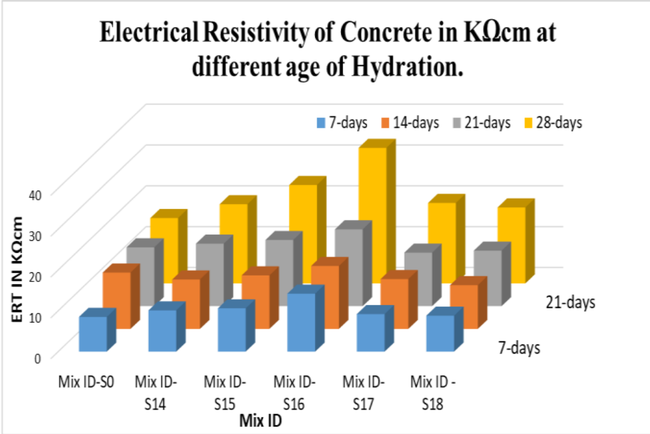

Figure-6: Electrical Resistivity of concrete mix with partial substitution of normal Portland cement with Fly ash at different age of hydration.

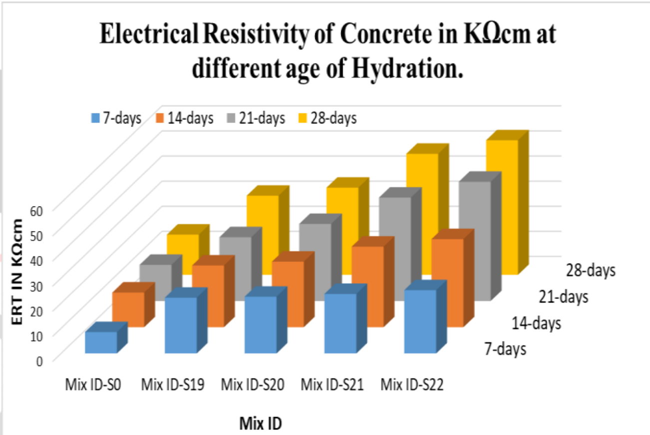

Figure-7: Electrical Resistivity of concrete mix with partial substitution of normal Portland cement with GGBS at different age of hydration.

VII. CONCLUSION

The following are the outcome of this research work.

I. The concrete resistivity is increasing with increase in age of hydration.

II. Concrete mix with partial substitution of Portland cement with GGBS shows maximum electrical resistivity, thus the concrete with fine GGBS is more durable in against Chloride exposure due higher percentage of Aluminum oxide in GGBS which will help to bind the free chloride ions in concrete.

III. Concrete mix with Portland Pozzolana Cement (Fly ash based) as per IS-1489, P-1 & also mix with Portland Composite Cement of type CEM-II/B-M as per BSEN-197 ,P-1 shows higher level of electrical resistance as compared to concrete mix with normal Portland cement CEM-I.

IV. Concrete mix with lower w/c ratio shows higher level of Electrical resistivity, while concrete with higher level of w/c ratio shows lower level of electrical resistivity.

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V.There is no significant improvement in concrete resistivity by increasing normal Portland cement CEM-I in the mix as compared to mix with Blast furnace slag cement CEM-III/A, Portland composite cement CEM-II/B-M & Portland Pozzolana cement.

VI. Addition of GGBS in concrete mix along with normal Portland cement shows maximum Electrical resistivity at both early age & later age of hydration as compared to other pozzolonic material Fly ash.

VII. The Electrical resistance of the concrete governs the durability of concrete as the resistance is directly depend on the microstructural properties of concrete like pore size, shape, pore size distribution & its continuity from surface of concrete to internal core structure & also volume of solid phase in pore spaces that is why on increasing hydration age the volume of solid phase increases & thus the Electrical resistivity of concrete.

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